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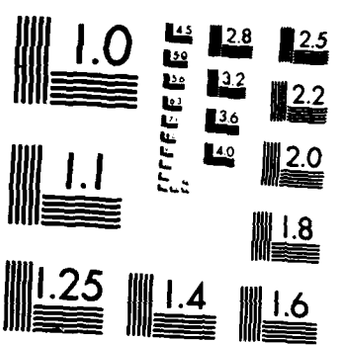

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ARE MASS EXTINCTIONS REALLY PERIODIC?*

by

Sheldon M. Ross[1]

ORC 86-19

October 1986

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ARE MASS EXTINCTIONS REALLY PERIODIC?

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Abstract - It is argued that the analysis of family extinction data that resulted in the claim of a 26$\frac{1}{2}$Myr periodicity of mass extinctions was flawed in that it did not allow for the possibility of a symmetric random walk model, which is shown to be perfectly consistent with the data.

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1. INTRODUCTION AND SUMMARY

In [1] Raup and Sepkoski analyzed data relating to the proportion of families that became extinct in each of 39 successive time periods of (average) length 6.2 million years. Stating that the data indicated a periodicity of mass extinctions, they then presented a statistical analysis which they claim verified the above.

In Section 2 of this note we point out that there was a basic flaw in the statistical analysis given in [1] since it did not allow for the possibility that the data was generated by a random walk model. In Section 3 we show that the random walk model is perfectly consistent with the data presented in [1].

2. A CRITIQUE OF THE STATISTICAL ANALYSIS IN [1]

In verifying that the data implied a periodicity in mass extinctions, Raup and Sepkoski computed the value of a statistic which is indicative of data periodicity, and then compared this value with its set of possible values under all permutations of the 39 data values. However, such a permutation test is only meaningful if the set of alternative hypotheses are such that, conditional on the set of data values, all 39! possible orderings are equally likely. That is, such a test is meaningful if one is testing periodicity against the alternative hypothesis that the data values constitute a random sample from some arbitrary probability distribution. It is not a meaningful test if the alternative is that the incremental changes of the data constitute

a random sample -- the so-called random walk model. Indeed, as the random walk model appears to be the usually assumed model for extinction (as mentioned in [2], [3], [4], and even in [1] since a random walk model would arise from a standard birth-death model when analyzed in discrete time) this appears to be a serious oversight.

We will now present a nonparametric analysis which indicates that the random walk model is perfectly capable of explaining the perceived periodicity of mass extinctions. Indeed, as mentioned in [2] and [3] the appearance of such a periodicity is quite possibly solely a function of the definition of an extinction peak.

3. ANALYZING THE VIABILITY OF THE SYMMETRIC RANDOM WALK MODEL

Raup and Sepkoski defined an extinction peak to occur at time period i if $D_{i-1}<D_i>D_{i+1}$ where D_i represents the data value for period i. That is, an extinction peak occurs each time a data value is larger than both its neighbors. Suppose now that the data was actually generated by a random walk mechanism so that each value had probability 1/2 of being greater and probability 1/2 of being less than its predecessor. As noted in [2] and [3] this would imply that any given time period will constitute an extinction peak with probability 1/4, and so, on average, such peaks would occur one-fourth of the time. However, as also noted in [2], there is some variance involved and so the above by itself does not indicate that the symmetric random walk model is consistent with the data of [1]. We will now show that this is the case.

To test the symmetric random walk hypothesis note first that it implies that the successive times between extinction peaks are independent random variables with the common distribution

$$P\{X=k\} = \frac{k-1}{2^k} \quad , k \geq 2 \qquad (1)$$

where X denotes the number of time periods between peaks -- for instance, X will equal 2 if there are peaks at periods r and r+2. Equation (1) is verified by noting that X will equal k if for some i, i=0,...,k-2, the first i incremental values following a particular extinction trio are negative, the next k-1-i are positive, and the next one is negative. The mean and variance of X are

$$E[X] = Var(X) = 4$$

We will now test the symmetric random walk hypothesis by performing a goodness of fit test on the times between successive extinction peaks for the data in [1]. As a prelude, say that an interpeak time X falls in region i if X=i+1 ,i=1,2,3,4 and in region 5 if X≥6, and note that

$$p_1 = P\{X=2\} = .25$$

$$p_2 = P\{X=3\} = .25$$

$$p_3 = P\{X=4\} = .1875$$

$$p_4 = P\{X=5\} = .125$$

$$p_5 = P\{X \geq 6\} = .1875$$

Now the 11 values of the time periods between successive extinction peaks given in [1] are 3,4,4,2,2,3,3,4,5,5,4. Hence, letting N_i denote the number falling in region i, we have that

$$N_1=2,\ N_2=3,\ N_3=4,\ N_4=2,\ N_5=0$$

The value of the goodness of fit test statistic is therefore

$$T = \sum_{i=1}^{5} (N_i - 11p_i)^2 / 11p_i = 4.394$$

As it is not apparent that the sample size 11 is large enough to suppose that T will, under the symmetric random walk hypothesis, have approximately a chi-square distribution with 4 degrees of freedom, the probability that T would have been as large as 4.394 when the distribution is given by (1) was determined by a simulation study using 10,000 runs. The results of this simulation were that this probability (commonly referred to as the p-value) is equal to .3438. (The chi-square approximation would have yielded the value .3547). Therefore, a deviation from the random walk fit as large as observed would be expected to occur 35% of the time when the random walk model is correct; thus showing that the symmetric random walk hypothesis is perfectly consistent with the data of [1].

Remark: The distribution of times between peaks given by (1) was also independently noted in [5] where goodness of fit tests relating to the mean and variance (but not the distribution function as done above) were presented.

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